



AEROSPACE INFORMATION REPORT

AIR7358™

Issued

2021-11

Calculations and Background Information Used
to Specify the Dimensions in AS6235

RATIONALE

A document was desirable to capture the information previously included in Appendices A, B, C, and E of AS6235A. This document fulfills that need.

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Documents

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1. SCOPE

This SAE Aerospace Information Report (AIR) contains a description of the design approach, the calculations, some comparisons to alternate SAE Aerospace Recommended Practice (ARP) documents, and the background information used to generate the standard face seal gland dimensions specified in AS6235.

NOTE: This AIR should be read in conjunction with AS6235. In some instances, the information contained within AS6235 is repeated for clarity.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275 °F (135 °C)
AMS-R-83485	Rubber, Fluorocarbon Elastomer, Improved Performance at Low Temperatures
ARP490	Electrohydraulic Servovalves
ARP1234	Static Axial O-Ring Seal Applications without Anti-Extrusion Devices for Engine and Engine Control Systems
AS568	Aerospace Size Standard for O-Rings
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
AS4716	Gland Design, O-Ring and Other Seals
AS4873	Gland Design, Elastomeric O-Ring Seals, Static Radial and Face 800 psi Maximum Service
AS5857	Gland Design, O-Ring and Other Elastomeric Seals, Static Applications
AS6235	Face Seal Gland Design, Static, O-Ring and Other Seals for Aerospace Hydraulic and Pneumatic Applications

2.1.2 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-P-25732	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Limited Service At 275 °F (135 °C) (Inactive)
MIL-PRF-5606	Performance Specification: Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base NATO Code Number H537
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

2.1.3 NAS Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NAS1613 Packing, Preformed, Ethylene Propylene Rubber

2.1.4 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO 3601-2 Fluid Power Systems - O-Rings - Part 2: Housing Dimensions for General Applications

2.1.5 Other Publications

The following publications are provided in Appendix A:

1. Presentation to AMS-CE, "Swell of O-Rings in Glands Compared to Conventional Volume Change Measurements," by Dr. W.R. Keller, dated August 2005.
2. Report "Swell of O-Rings in Glands Compared to Conventional Volume Change Measurements; Updated Test Results on NBRs in Red Hydraulic Oils," by Dr. W.R. Keller, dated 14 June 2013.
3. Report "Finite Element Analyses of Face Seal Glands, Internal Pressure, SAE AS6235 Design Standard Support" by Dr. W.R. Keller, dated 21 April 2015.

2.2 Definitions

GLAND: This is the assembly of the component with a recess to contain the sealing element and the adjoining flat pressure-retaining plate in close contact with it.

GROOVE: This is the recess machined in one component that contains the sealing element.

NOTE: The terms gland and groove are not interchangeable in this document.

3. GLAND DETAILS

3.1 Internal and External Pressure Glands

The glands specified in AS6235 are for static face seals and have been specifically designed for aerospace fluid power applications using actual data obtained from testing the specific elastomer materials and fluids used in aerospace fluid power applications.

The configuration of the seal and placement of the seal within the gland depends on the direction of pressure. The axial seals may be pressurized from a source located within the seal's inner diameter (internal pressure application) or from a pressure source located outside the outer diameter of the seal (external pressure application). See Figures 1 and 2, respectively.

3.2 Gland and Groove Dimensions

NOTE: The groove dimensions specified in AS6235 do not support the mounting interface patterns described in ARP490. The requirements of this standard should not be applied to the seal grooves designed to ARP490 pattern recommendations.

The gland design configurations are per Figures 1, 2, and 3. Refer to AS6235 for detailed dimensional requirements and tolerances for ØA, ØB, G, L, and R.

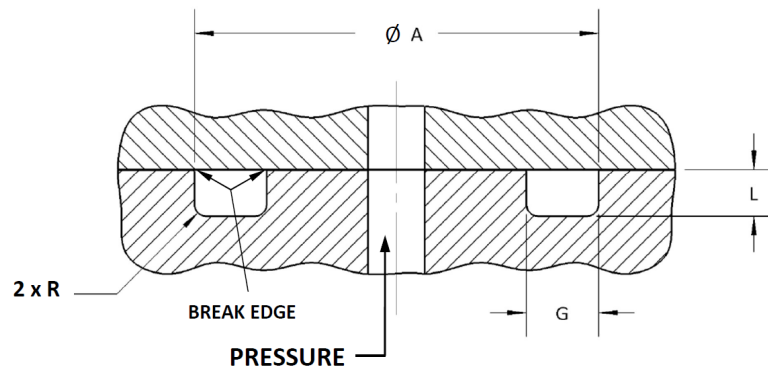


Figure 1 - Gland for internal pressure

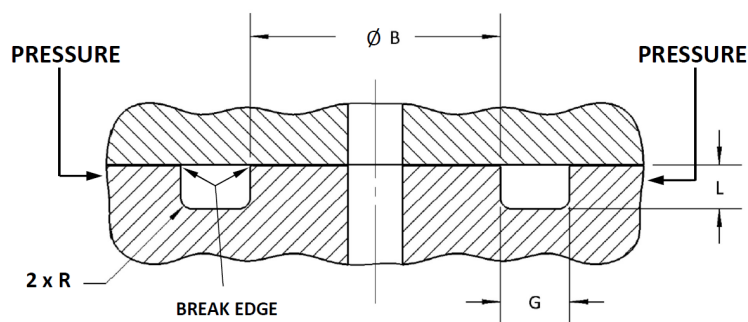


Figure 2 - Gland for external pressure

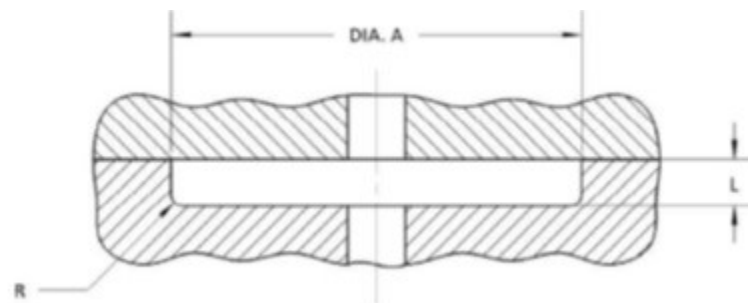


Figure 3 - Gland without an internal wall

NOTES:

1. Glands for internal pressure applications to Figure 3 are generally not recommended; gland designs to Figure 1 protect the seal against any flow erosion and are required unless the seal is designed with a metal or suitable high modulus plastic internal protecting component.
2. Some internal pressure seal designs incorporate a metal or high modulus plastic component on the ID to prevent flow erosion, in which case grooves to Figure 3 may be used.
3. External pressure applications should also use closed glands to protect seals from the environment unless there is a separate component to protect the seal OD.
4. Seals using these gland configurations should be tested to prove suitability.

The gland dimensions and tolerances specified in AS6235 in many cases differ from other face seal specifications. They were calculated using a more scientific approach by including data for elastomer swell in the applicable fluids and relevant thermal expansion from actual testing rather than, for example, an arbitrary 30% as used in ARP1234.

The groove depths have been sized using standard O-rings to AS568 with associated Class 2 tolerances, to provide sufficient squeeze for effective sealing in line with AS5857 (i.e., 10% minimum squeeze), but not to exceed a maximum squeeze of 25% before any swell and at ambient temperature. Appendix A explains why the tolerances on groove depths used in AS6235 are necessary for the squeeze to remain within the 10 to 25% range as opposed to the groove depth tolerances recommended, for example, in ARP1234.

3.3 Supporting Information

Further differences from other face seal gland specifications in calculating groove diameters are as follows:

- a. For internal pressure applications, the groove major diameters $\varnothing A$ have been determined by limiting cramping (diametric compression) to 1% of the O-ring OD based on O-ring nominal dimensions while under nominal squeeze.
- b. For external pressure applications, the groove minor diameters $\varnothing B$ have been determined by limiting diametric stretch to 5% of the O-ring ID based on O-ring nominal dimensions while under nominal squeeze.

Both of these limitations are in line with common industry practice.

The gland volume occupancy including volume swell and thermal expansion is generally limited to 95% maximum.

The O-ring volume swell while under compression (squeeze) uses calculations determined from a study presented to AMS-CE Committee.

The calculations to determine the groove dimensions use the combined characteristics of fluid volume swell and thermal expansion to result in the greatest increase in O-ring volume by each dash size.

Closed glands are required, with exceptions.

4. VOLUME OF AN O-RING DUE TO SWELL FROM FLUID EFFECTS AND THERMAL EXPANSION

The glands specified in AS6235 account for O-rings under the effects of both volume swell while under squeeze and thermal expansion. This differs from previous face seal specifications which do not calculate these factors.

A particular elastomer material was chosen which produced a combination of volume swell in a particular fluid and thermal expansion for the same material resulting in the greatest increase in volume. Volume swell is dependent on the amount of squeeze applied in that as more squeeze is applied, then the amount of volume swell due to interaction with the particular fluid to which the O-ring is exposed is limited.

The O-ring volume swell due to fluid exposure is determined by applying a formula determined by testing and submitted in a presentation to SAE AMS-CE Committee (see Appendix A):

$$\text{Volume change under squeeze } V_c = 1.958 + (0.648 \times V_f) - (0.0156 \times V_f \times S) \quad (\text{Eq. 1})$$

where:

V_f % = free volume change in fluid (from material data sheets)

S = % squeeze in the gland

NOTE: Enter V_f and S as whole numbers, the resulting volume swell in fluid and under squeeze V_c will be a whole number. After calculating squeeze, swell is calculated for each O-ring using Equation 1.

The minimum O-ring axial squeeze at ambient temperature (taken as 75 °F (23.9 °C)) to this standard is 10% per AS5857. Since O-ring volume swell decreases as squeeze is increased, 10% squeeze will render the greatest volume swell.

Where O-ring cross-section tolerances are at the maximum and groove depths are at the minimum, these circumstances will generate maximum squeeze and hence will generate the lowest volume swell. The set of circumstances found to generate the largest O-ring volume is with the O-ring dimensions on maximum and the groove depth on maximum, along with thermal expansion (see Appendix A).

5. DETERMINATION OF ELASTOMER USED IN CALCULATIONS

The swell and the coefficient of thermal expansion (CTE) combinations are based on using the following elastomers and fluids:

- NAS1613 elastomer in high and low-density phosphate ester fluids per AS1241.
- MIL-P-25732, AMS-P-83461, AMS-R-83485 all in MIL-PRF-5606, MIL-PRF-83282, and MIL-PRF-87257 fluids.

See details of elastomer swell and physical properties in Section A.2.

It should be noted that for calculation purposes it is essential to use the particular elastomer that has a combination of the greatest O-ring volume swell and volume thermal expansion. It is a false set of circumstances to use the greatest volume swell from all the fluid/elastomer tests and then use the greatest thermal expansion from the range of elastomers.

The elastomer to produce the greatest increase in volume from the total of its discrete fluid volume swell and thermal expansion is AMS-P-83461 elastomer tested in MIL-PRF-5606 for 70 hours at 275 °F (135 °C) resulting in a free swell of 16.3% and a CTE of 1.13×10^{-4} in/in/°F (2.03×10^{-4} mm/mm/°C).

A specific exclusion from this specification is all fluorosilicone elastomers. Due to a typical high CTE, this material is not suitable for use in grooves to this specification if used at the maximum operating temperature in the region of 350 °F (177 °C).

NOTES:

1. Where the squeeze is increased and/or the known swell and linear coefficient of thermal expansion for an alternate material exceed the limits stated above, the calculations shown in Section A.2 should be followed to calculate the minimum radial gland width required to achieve the maximum volume occupancy of 95%. Appendix A and Digital Annex A (Excel spreadsheet file) included with AS6235 may also be used to perform this calculation.
2. No accommodation has been made for thermal expansion or contraction of hardware.
3. The hardware dimensions that affect seal performance through temperature variation are principally the groove depths. At low temperatures, the seal material will shrink producing a loss in the squeeze. However, as the hardware will also shrink, the effect will not be quite so severe. Similarly, as the temperature increases the seal will expand, thereby increasing squeeze. However, as the hardware will also expand, the effect similarly will not be quite so severe. Since various materials are used for hardware, it is not possible to account for every material used for hardware; therefore, to take the worst possible case, no account is made for thermal effects of hardware dimensions in this standard.

6. NOTES

6.1 Revision Indicator

The change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE A-6C2 SEALS COMMITTEE

APPENDIX A - ELASTOMER BACKGROUND, TEST DATA, AND INTERPRETATION

A.1 PUBLICATIONS

- A.1.1 Report: "Swell of O-Rings in Glands Compared to Conventional Volume Change Measurements" by Dr. W.R. Keller, dated August 2005.

Test Report

Authors: Robert W. Keller

Date: 31-August 2005

Title: Swell of O-Rings in Glands compared to conventional Volume Change Measurements

Purpose: To determine if there is a relationship between squeeze and volume change of O-Rings confined in their glands compared to conventional free volume change measurements per ASTM D471.

Results:

1. O-Rings under actual application squeeze swell considerably less than free swell conditions used in tests such as ASTM D471.
2. The more the squeeze of the O-Ring, the less the swell which does make sense.
3. A relationship between the swell of an O-Ring in the squeezed gland condition and the squeeze amount and free volume change determined by ASTM D471 was found as:
 - a. Squeezed swell = $1.95729 + (0.647765 \cdot VC) - (0.0155877 \cdot VC \cdot SQ)$ [1]
 - b. Where,
 - i. VC = free volume change determined by ASTM D471 immersion
 - ii. SQ = % squeeze of the O-Ring cross section, in the range of 5-35% squeeze.
4. The above relationship covers a variety of different polymer types and immersion fluids.
5. The above relationship can be used to predict the swell of actual O-Rings knowing the free volume change and the squeeze in the gland.

Recommendations:

1. Equation [1] above should be used to estimate the actual swell of O-Rings in their gland knowing the free volume change and the squeeze conditions in the gland.
2. While 25% is considered the maximum that materials can swell in the free state and still function properly as O-Rings (based on the assumption that the O-Ring gland has roughly 25% free volume available), a more realistic approach based on this data would suggest an upper swell limit for free volume change of 35%. This will yield an actual volume change in the O-Ring gland of roughly 23% at the condition of 5% squeeze in low squeeze applications. Lower actual volume changes of the O-Rings in glands will occur with higher squeeze levels.

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NOTE: The equation to determine volume change (swell) is dependent on squeeze and volume swell in fluid in the free condition.

Introduction

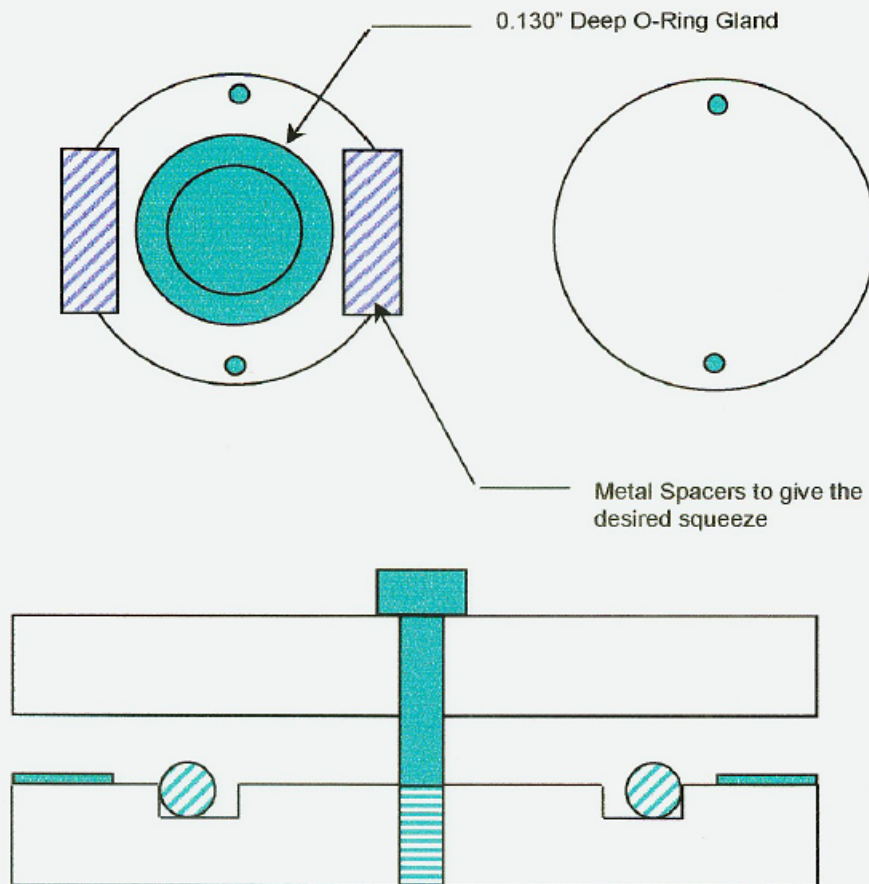
One question that continuously arises is “what swell can I expect of this O-Ring in this fluid in this gland at the operating temperature?” As a first estimate, most people will use the results determined from conventional immersion testing per ASTM D471 to answer that question. However, that would be a very crude approximation since the actual O-Ring in the gland is confined, under squeeze, and there is limited volume available for swelling. This paper summarizes several years of work on this subject using several different rubber materials and various fluids.

To measure the volume change of the free sample compared to an O-Ring in the gland, simple experimental test fixtures were made as shown in Figure 1. The width of the O-Ring groove was standard for the cross section (gland width = 0.285 ± 0.005 inches). An AS568-325 size O-Ring was selected for this study for the following reasons:

- The ring is large enough to give high reliability in volume change measurements per ASTM D471.
- The cross section of the ring is large enough to get accurate shim heights and very tightly controlled squeeze values in the fixture.
- The fixtures are small enough to fit inside convenient vessels for fluid aging at elevated temperatures.

The point of the work was to study the actual volume change of the seal in the gland compared to free volume change values determined through ASTM D471 techniques and to determine if there was a predictive model to more accurately estimate the volume change of actual seals in glands. For comparison, a freely suspended AS568-325 size O-Ring was immersed in the same test fluid to get the free volume change per ASTM D471.

FIGURE 1



Results and Discussion

The results are tabulated in Table 1 for the wide variety of materials and immersion conditions tested. Typical of the results are the relationships shown in Figures 1, 2, and 3. No matter what material or what immersion fluid was used, swell of the actual O-Ring in the gland was reduced by the amount of squeeze compared to free volume change measurements by ASTM D471. Additional squeeze caused less swell of the actual O-Ring. Intuitively, this makes sense since the O-Ring in the groove is under squeeze so it will act like a material with a much higher stiffness and the O-Ring is confined by the groove.

Figure 2

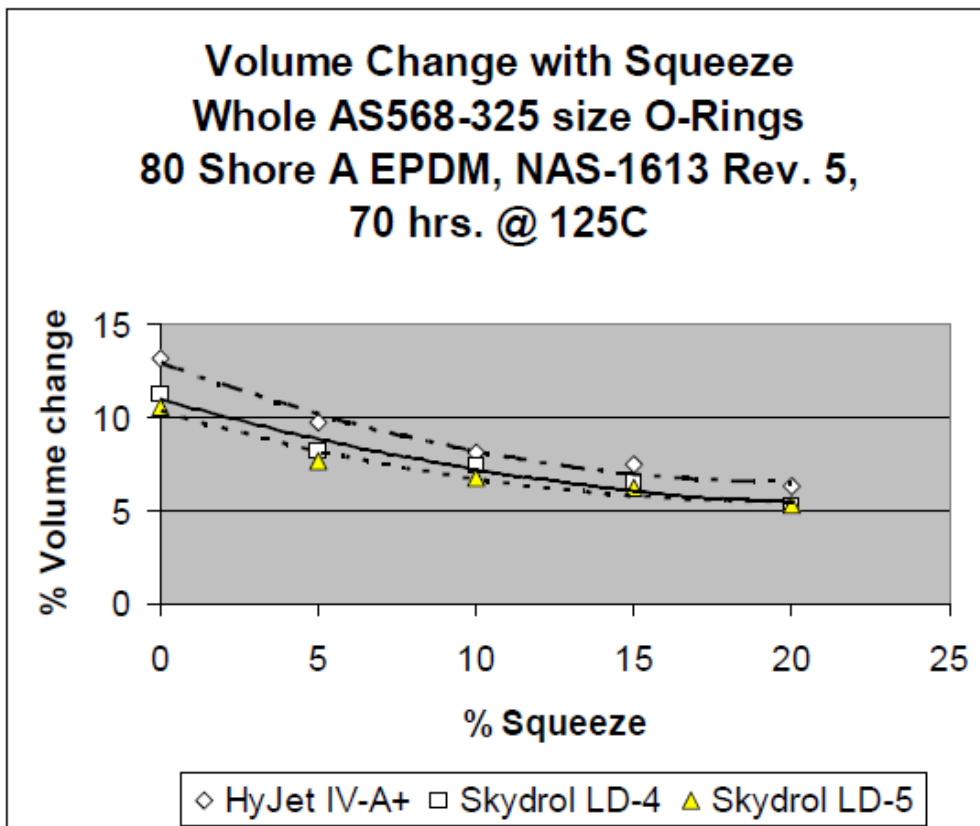


Figure 3

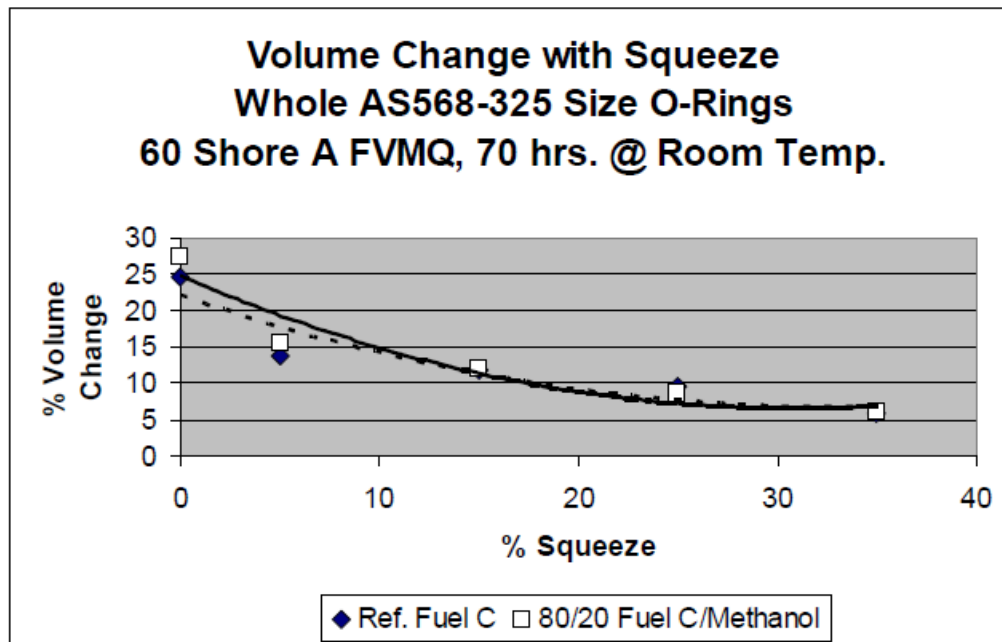
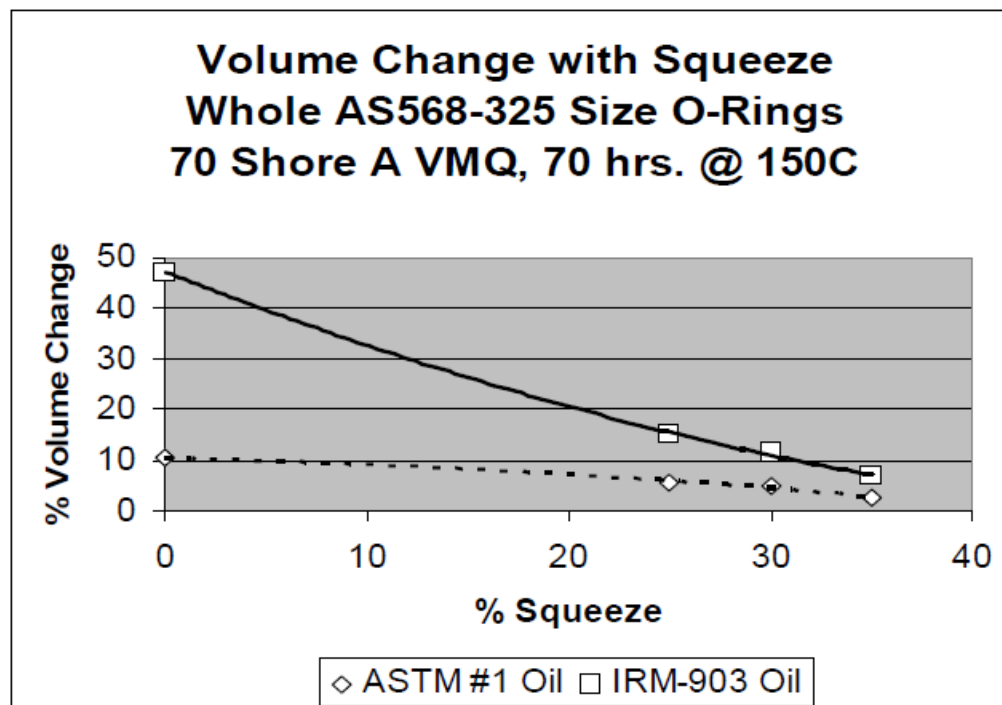


Figure 4



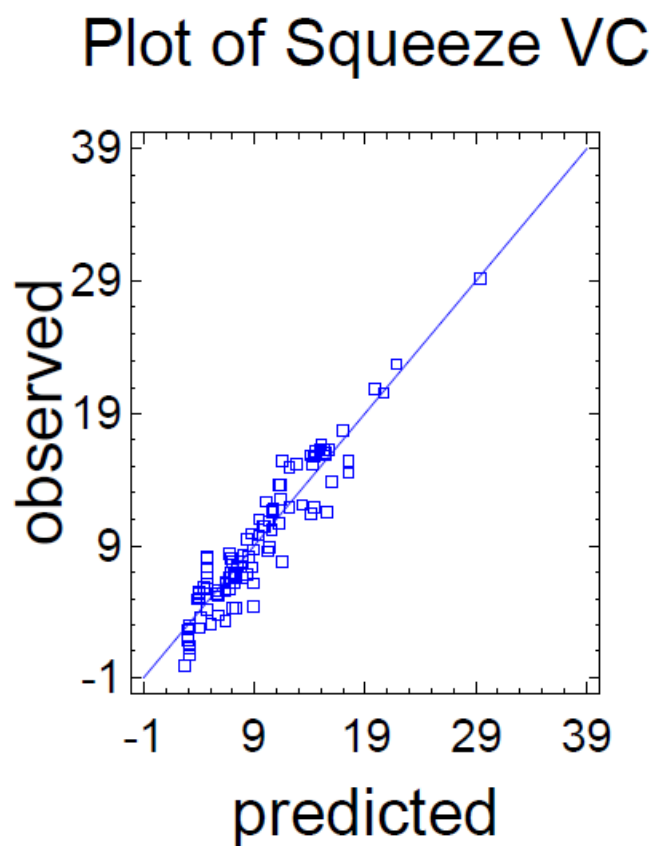
All of the data in Table 1 was analyzed to determine if a relationship consisted between the squeeze, free volume change, and volume change of the actual O-Ring in the groove. The results are given in Figure 5 below with the following statistics for the fit of the data:

R-Squared = 88.48 %

R-Squared adjusted for degrees of freedom = 88.26%

Standard error of estimate = 1.77

Figure 5



The resulting equation predicting the swell of the O-Ring in the gland based on known squeeze and free volume change determined by ASTM D471 is:

$$\text{Squeezed swell} = 1.95729 + (0.647765 * VC) - (0.0155877 * VC * SQ) \quad [1]$$

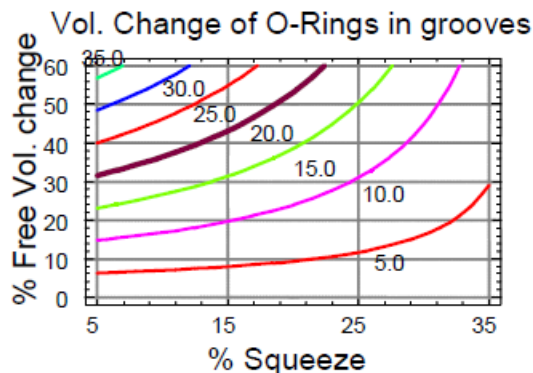
- Where,
 - VC = % volume change determined by ASTM D471 immersion tests
 - SQ = % squeeze of O-Ring cross section
 - Squeezed swell = measured swell of whole O-Ring in gland.

The utility of Equation [1] is:

- It utilizes current data available for many materials in conventional test reports
 - For example, if the volume change of an NAS-1613 EPDM compound in Skydrol LD-4 is reported as +11.3% after 70 hours @ 125C immersion, and the application maximum squeeze of the O-Ring is 18.0%, then Equation [1] predicts that the swell of the O-Ring in the application will be $6.11\% \pm 1.77\%$.
 - If the ring used in the example above is exposed to 22.5% squeeze in the application (considering a design change), Equation [1] predicts that the swell of the O-Ring in the application will be $5.31 \pm 1.77\%$.
- Generally, Squeeze min., max., and nominal can be determined from the tolerance stack of the O-Ring and the gland.
- No “new” data need be generated to use this equation.

This equation is also plotted in Figure 6 as a contour plot for estimations.

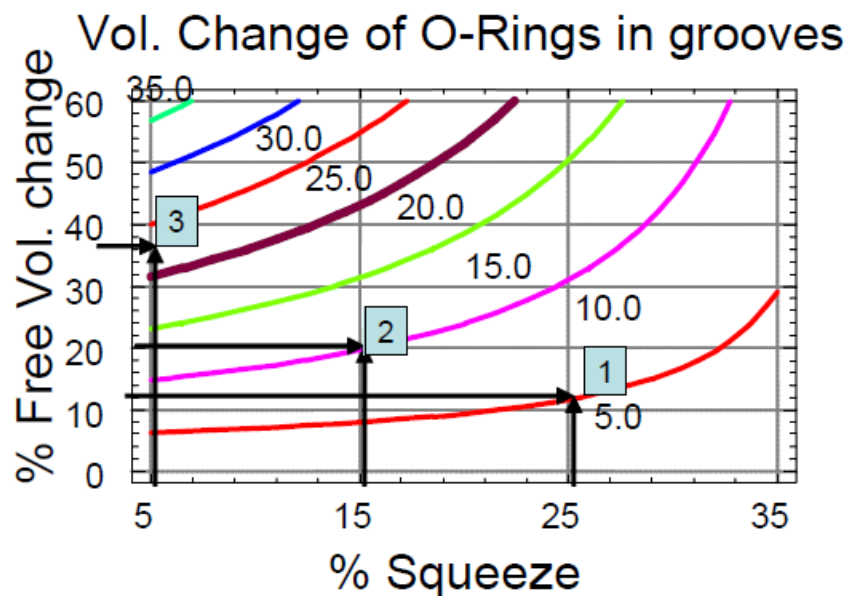
Figure 6



If we used Figure 6 and the data for our first O-Ring example:

- 11.3% free volume change per ASTM D471 in Skydrol LD-4, 70 hours @ 125C
- 18.0 % max. squeeze in the application

Figure 7



Example 1 = 25% squeeze, 12% free volume change, predicted actual vol. change in gland = 5.0%

Example 2 = 15.0% squeeze, 20.0% free volume change, predicted actual vol. change in gland = 10.0 %

Example 3 = 5.0 % squeeze, 37% free volume change, predicted actual vol. change in gland = roughly 22.2%

Estimate from Contour plot of actual volume change of O-rings in actual groove applications (blue squares as examples).

The function is also plotted in Figure 8 as a Surface plot.

Figure 8

Vol. change of O-rings in glands

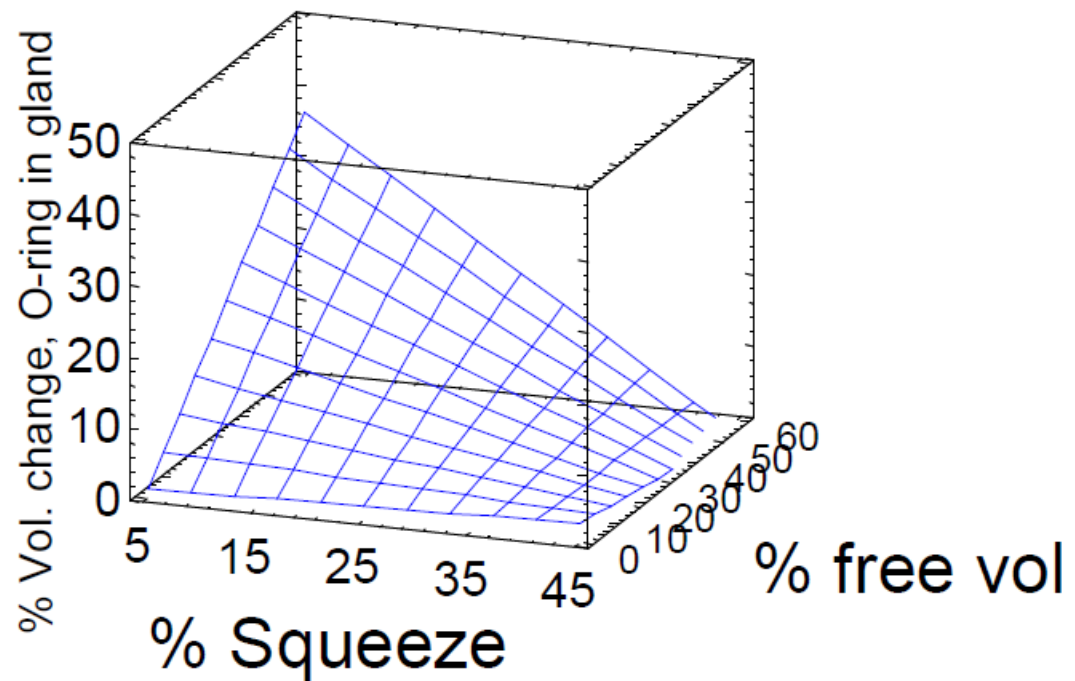


Table 1

% Squeeze	% Free Vol. Chg.	% Vol. Chg. In groove	Description
5	18.0	14.9	70 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
15	18.0	11.0	70 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
25	18.0	5.8	70 duro FVMQ in Ref. Fuel C, 70 hours @ Room Temp.
5	16.9	7.7	70 duro FVMQ in Ref. Fuel B, 70 hours @ Room Temp.
15	16.9	4.4	70 duro FVMQ in Ref. Fuel B, 70 hours @ Room Temp.
25	16.9	3.3	70 duro FVMQ in Ref. Fuel B, 70 hours @ Room Temp.
5	33.0	20.6	Fuel Resistant 70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	33.0	16.3	Fuel Resistant 70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	33.0	10.2	Fuel Resistant 70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
5	23.0	16.7	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
15	23.0	15.5	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
25	23.0	6.5	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
5	12.2	6.1	Fuel Resistant 70 duro NBR in Ref. Fuel B, 70 hours @ Room Temp.
15	12.2	4.3	Fuel Resistant 70 duro NBR in Ref. Fuel B, 70 hours @ Room Temp.
25	12.2	3.1	Fuel Resistant 70 duro NBR in Ref. Fuel B, 70 hours @ Room Temp.
5	48.0	29.1	70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	48.0	22.7	70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	48.0	11.9	70 duro NBR in 85/15 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
5	-0.57	0.16	70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.
15	-0.57	0.02	70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.
25	-0.57	0.04	70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.

Table 1 (continued)

% Squeeze	% Free Vol. Chg.	% Vol. Chg. In groove	Description
5	-1.7	-0.4	Fuel Resistant 70 duro NBR in Ref. Fuel A, 70 hours @ Room Temp.
15	-1.7	-0.4	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
25	-1.7	-0.5	Fuel Resistant 70 duro NBR in Ref. Fuel C, 70 hours @ Room Temp.
5	31.4	20.8	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
15	31.4	16.2	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
25	31.4	12.3	60 duro FVMQ in 80/20 Ref. Fuel C/Methanol, 70 hours @ Room Temp.
5	26.3	17.7	60 duro FVMQ in 80/20 Ref. Fuel C/Ethanol, 70 hours @ Room Temp.
15	26.3	15.2	60 duro FVMQ in 80/20 Ref. Fuel C/Ethanol, 70 hours @ Room Temp.
25	26.3	9.9	60 duro FVMQ in 80/20 Ref. Fuel C/Ethanol, 70 hours @ Room Temp.
25	10.8	8.2	70 duro VMQ in ASTM #1 Oil, 70 hours @ 150C
30	10.8	4.9	70 duro VMQ in ASTM #1 Oil, 70 hours @ 150C
35	10.8	0.7	70 duro VMQ in ASTM #1 Oil, 70 hours @ 150C
25	52.3	16.0	70 duro VMQ in IRM-903 Oil, 70 hours @ 150C
30	52.3	12.5	70 duro VMQ in IRM-903 Oil, 70 hours @ 150C
35	52.3	4.2	70 duro VMQ in IRM-903 Oil, 70 hours @ 150C
20	24.5	8.6	High performance, 70 duro CR in HCFC-123, 70 hours @ 100C
20	20.5	7.3	High performance, 80 duro CR in HCFC-123, 70 hours @ 100C
25	24.5	6.8	High performance, 70 duro CR in HCFC-123, 70 hours @ 100C
25	20.5	6.7	High performance, 80 duro CR in HCFC-123, 70 hours @ 100C
30	24.5	5.6	High performance, 70 duro CR in HCFC-123, 70 hours @ 100C
30	20.5	5.6	High performance, 80 duro CR in HCFC-123, 70 hours @ 100C